

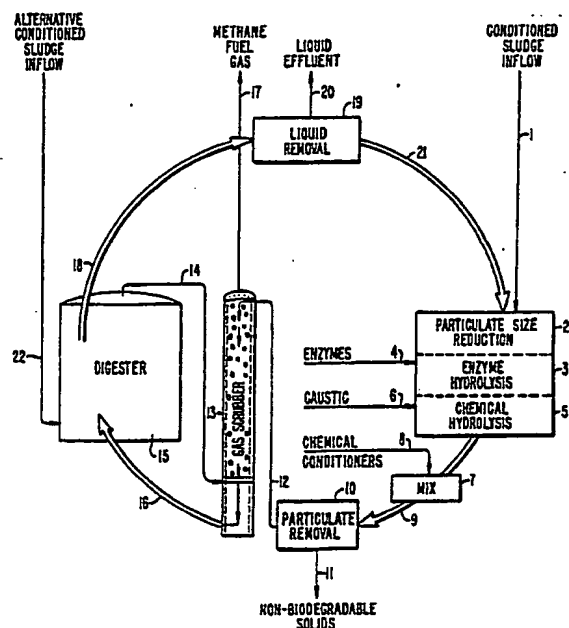


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(54) Title: SLUDGE RESTRUCTURING AND CONVERSION METHOD**(57) Abstract**

A method for the restructuring of wastewater treatment sludges and conditioned solid wastes (1) to remove non-biodegradable solids and to convert biodegradable matter into methane fuel gas (17). The restructuring process includes particulate size reduction (2), enzyme hydrolysis (3), alkaline chemical hydrolysis (5), and removal of non-biodegradable particulate matter (10), including metallic hydroxides. The resultant BioFeedstock (12) includes biodegradable matter in solubilized form suitable for rapid metabolism in biological reactions, including anaerobic digestion (15). Intermediate chemical reactions are employed to refine the digester biogas (14) into higher grade methane fuel gas. The intermediate biological treatment sludges are reconstructed and recycled as additional BioFeedstock. The separated non-biodegradable particulate matter (11) is discharged as a biologically inert concentrate.



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SLUDGE RESTRUCTURING AND CONVERSION METHOD

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BACKGROUND OF THE INVENTION

This is a continuation-in-part patent application related to our prior patent application filed on December 8, 1986, U.S. Patent Office Serial Number 06/939,231, which in turn is a continuation of U.S. patent application Serial No. 06/791,186, filed October 25, 1985, now abandoned.

This invention relates to improvements to known methods for biological purification of wastewaters by removal of solids, part of which are converted into methane gas with the remainder being a residue sludge in which potentially biodegradable matter comprises typically more than 50% of the original waste solids. Our invention provides methods for restructuring, recycling, and converting substantially increased proportions of biodegradable matter into methane fuel gas with a corresponding reduction of biodegradable matter discharged as residue sludge.

For example, the methods of our invention are adaptable to the improvement of Municipal Wastewater Treatment Plant processes to increase on site conversion of biodegradable matter into fuel gas and to reduce substantially the volume, biodegradability, moisture content, and pathogen content of the residue sludge.

For example, the methods of our invention are adaptable to converting the biodegradable fraction of Municipal Solid Wastes into methane fuel gas with a corresponding reduction in the volume and biodegradability of the waste residue.

Municipal Wastewater Treatment Sludges, are the Conditioned Sludge residues removed in purification of municipal wastewaters in modern Publicly Owned Treatment Works (POTW).

Wastewater Influent is usually processed through screens and degritting equipment to remove rags and other debris, including rocks and heavy granular material. The wastewater is then treated to separate
5 solids, including Primary Treatment Sludge (usually gravity precipitated) and Secondary Treatment Sludge or Waste Activated Sludge, usually precipitated following aerobic treatment.

Usually such intermediate process sludges are
10 stabilized in an anaerobic Digester in which about 50% of the biodegradable matter is converted into Digester Gas, or Biogas, containing about 60% Methane and about 40% carbon dioxide and other non-fuel gases. The residue Digester Sludge (usually 2-3% solids) is dewatered
15 and discharged as Wastewater Treatment Sludge, usually containing substantial amounts of chemicals which had been added to facilitate dewatering prior to disposal.

Usually over 50% of digester sludge is undigested organic matter including biologically fresh anaerobic microbial biomass. According to U.S.A. Environmental Protection Agency (EPA) publications, Coliform bacteria is present at typical concentrations of 30,000 to 6,000,000 per 100 milliliters, viral pathogens at 100-1,000 per 100 ml, and Salmonella at 3-62 per 100
25 ml. The parasite *Ascaris Lumbricoides* survives digester treatment and is found in concentrations up to 1,000 per 100 ml.

U.S. government investigators report heavy metals in digester sludge from cities in the United
30 States at the following median (dryweight) concentrations:

	Cadmium	31 mg/kg
	Chromium	1,100 mg/kg
	Cobalt	100 mg/kg
	Copper	1,230 mg/kg
5	Lead	830 mg/kg
	Mercury	6.6 mg/kg
	Nickel	410 mg/kg
	Silver	100 mg/kg
	Zinc	2,780 mg/kg

10 The costs of dewatering and disposing of this
volatile organic material in an ecologically acceptable
way are more than \$150.00 per dryweight ton in many
areas of the United States. Agricultural usage and
incineration are restricted by the content of toxic
15 heavy metals and other constraints. Sludge production
and the costs of sludge processing-to-disposal are ex-
pected to increase substantially during the next decade.

POTW sludges are notoriously difficult to
dewater because of their content of gelatinous material
20 and microbial cell structures which remain intact, both
of which tenaciously retain water and immobilize micro-
particulates by adsorption and absorption.

Municipal Solid Wastes (MSW) are the major
source of biodegradable organic materials from urban
25 areas, being produced at an annual rate of about 40,000
dryweight tons per 100,000 population. Also produced
annually is about 20,000 tons of MSW inorganic and non-
biodegradable material. Most of this material is cur-
rently disposed of in landfills; however, disposal costs
30 are increasing because of a developing shortage of con-
venient disposal sites and the need to control seepage
of effluents containing heavy metals and other toxins.
MSW incineration is an alternative method of stabiliza-
tion and energy recovery; however, in some areas it is
35 unacceptable to discharge into public airspace the re-
sidual products of combustion which may include vapor-
ized heavy metals and toxic organic compounds.

The energy potential of the 50-70% biodegradable fraction of MSW is illustrated by the fact that this material, over a period of years, converts to biogas by anaerobic bacterial decomposition within the landfills. This may result in the potentially hazardous seepage of gases from such sites and seepage of leachate containing heavy metals and other toxins into the ground water. At some of these MSW disposal sites, accumulating biogas is removed through wells and refined to utility grade methane fuel gas.

The potential biochemical energy content of MSW cellulose is described by Paul F. Bente, Jr., Executive Director of the Bio-Energy Council, Arlington, Virginia, on page 178 of the Bio-Energy Directory and Handbook - 1984: "The single largest source of partially pretreated cellulosic feedstocks is MSW. It is collected and available year round. From 50-75% of MSW has materials with 50 percent or more cellulose, whereas naturally occurring lignocellulosic materials have only about 30-45%. The high cellulose content occurs because the MSW contains much waste paper in which the cellulose portion has been both pretreated and enriched by the paper pulping process."

Resource Recovery technologies are well known for classifying MSW to remove non-biodegradable objects, including metals, glass, ceramics, rocks, plastic, and rubber. The remaining, mostly biodegradable, material may be further processed into a Conditioned Sludge containing 5-10% solids suitable for restructuring and conversion into methane fuel gas according to the method of our invention.

SUMMARY OF THE INVENTION

This invention relates to methods for improving the operation, effectiveness, and capacity of conventional municipal and industrial wastewater treatment plants employed for purification of water containing

organic wastes. A major feature of the method of our invention involves the restructuring of conditioned conglomerate sludges by disintegrating the biodegradable fraction into soluble form. Such restructuring facilitates removal of non-biodegradable particulates, including metals, grit, fibrous material, and other inert waste. A specific process sequence is described:

(i) Particulate Size Reduction: This process step includes the use of grinding, comminuting, and homogenizing machines to accomplish progressive particulate size reduction and dispersal of the sludge solids.

(ii) Enzyme Hydrolysis: The in-process sludge flows into a reactor into which hydrolytic enzymes are added. In the resultant reaction, contact between the enzymes and the dispersed particulate matter results in the hydrolysis of the polysaccharide gel fraction of the sludge and also serves to hydrolyze or degrade cellular and particulate organic matter by disintegrating large molecular structures into smaller components. This hydrolytic preconditioning is an important intermediate step in the method of our invention since biodegradable material is conditioned into dispersed forms that will react readily in our subsequent chemical hydrolysis step.

(iii) Chemical Hydrolysis and Conversion of Metals into Hydroxides: The final step in hydrolyzing the organic matter is an alkaline hydrolysis reaction. Microbial life-forms are destroyed, and soluble metals are converted into metallic hydroxides. Practically all the biodegradable matter is converted into soluble form. Because of the prior preconditioning by enzyme hydrolysis, the desired solubilization of biodegradable matter into solubilized peptides and amino acids is completed rapidly at relatively low temperatures and with relatively low concentrations of caustic chemicals, thus conserving nutrients for subsequent conversion reactions.

(iv) Residual Solids Removal: A centrifuge may be used to remove suspended solids which are biologically inert or which cannot be converted economically into digester gas. Such solids include metals, metallic hydroxides, grit, ash, biologically resistant fibers and biodetritus. Since all cellular and gelatinous matter has been disintegrated, the residual particulate solids are readily separable and have a relatively low capacity for retention of water. Centrifuge cake is produced at 20-25% solids. The residual sludge can be dewatered to 40% solids or more in a filter press operating at relatively moderate pressure. The residue is inert, practically free of biological activity, and may contain a substantial proportion of resins and resin-coated cellulose fibers. This residue may be economically reduced to a low-volume ash concentrate by incineration.

(v) BioFeedstock: The intermediate BioFeedstock thus produced includes practically all the treated biodegradable material in soluble form as defined by Standard Methods for the Examination of Water and Wastewater, 16th Edition, (1985), American Public Health Association, et al, Washington. This intermediate product is biologically inactive since the pH is about 10.0 and practically all the microbial cell structures have been disintegrated.

The method of this invention includes the means for purification of digester biogas produced on site. The alkaline characteristic of the intermediate BioFeedstock is neutralized by infusion and absorption of the acidic carbon dioxide content of the digester biogas. Hydrogen sulfide and other impurities are removed in this gas scrubber step. The desirable results obtained are neutralization of the BioFeedstock to about pH 7.5 and enhancement of the energy content of the biogas by removal of the non-fuel constituents from the gas produced.

The method of this invention includes the means to increase substantially the inflow feed processing capacity and biogas production capacity of anaerobic digesters. Tests show that the solubilized nutrient BioFeedstock of this invention is metabolized at a rate approximately eight times faster than for metabolization of typical feedstocks comprising primary or secondary treatment sludges.

The method of this invention includes the means to increase substantially the recovery of energy in the form of methane gas by restructuring and converting the biodegradable fraction of wastewater treatment sludge and municipal solid wastes usually disposed of as wastes.

The method of this invention is adaptable to improving the functioning of wastewater treatment facilities by restructuring recycled, intermediate, biologically-reactive sludges into biologically compatible nutrient BioFeedstocks.

The method of this invention includes the means to reduce substantially the volume and biodegradability of wastewater treatment sludge and municipal solid wastes usually disposed of as wastes.

A major environmental objective is to reduce pollution inherent in the land disposal or incineration of municipal wastewater sludges and solid wastes.

A major economic objective is to save capital and operating costs otherwise required for treatment-to-disposal of municipal wastewater sludges and solid wastes.

Other features and innovations will be described in the following discussion of the drawings illustrating the preferred embodiments of our invention.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a flow diagram which illustrates the method of our invention for restructuring

conditioned sludges into high quality methane fuel gas, a low moisture residue of non-biodegradable solids, and a liquid effluent with a low solids content.

Figure 2 is a flow diagram which illustrates the method of our invention adapted to the functioning of a municipal wastewater treatment facility to decrease the production of disposal sludge and to increase the production of methane fuel gas.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, there is indicated a source of conditioned biodegradable sludge inflow 1. Suitable urban biomass sources of biodegradable materials include sewage sludges from wastewater treatment plants and the biodegradable fraction of municipal solid wastes (garbage). Other sources may include residues from food and beverage processing and manures from agricultural animals and fowl. Such biomass materials may be conditioned by methods well known in the art into aqueous slurries containing 5-10% (dryweight) solids with particulates not exceeding about 0.25 inch in diameter and from which relatively high specific gravity particulates such as glass, ceramics, rubber, rocks, and sand have been removed.

Particulate Size Reduction processing 2 may include the use of grinding, comminuting, and homogenizing machines, well known in the art, to accomplish progressive particulate size reduction and dispersal of the sludge solids. Typically, the resultant size range of granular particulates in the sludge will be less than 20 microns in diameter, and the length of smaller diameter fibrous particulates will range up to about 50 microns.

The in-process sludge flows into an Enzyme Hydrolysis reactor 3 into which a solution of hydrolytic enzymes is added at 4. In the resultant reaction, contact between the enzymes and the dispersed particulate matter results in the hydrolysis of the polysaccharide

gel fraction of typical waste sludges and also serves to hydrolyze or degrade particulate organic matter. The sludge should be recirculated or mixed as necessary to facilitate contact between the enzymes and the particulate solids. The enzyme hydrolysis reaction may be accomplished most effectively within the pH range 6.5 to 7.2 and the temperature range 20°C to 55°C maintained for four to ten hours in a reactor including a recirculation mixer. The effectiveness of the hydrolytic reaction increases with temperature and time, and these factors should be adjusted to the characteristics of the raw sludge to be processed while taking economics into consideration.

The final step in hydrolyzing the organic matter is a Chemical Hydrolysis reaction 5. Caustic chemicals are added at 6, usually sodium hydroxide, sodium carbonate, potassium hydroxide, or potassium carbonate, in quantity sufficient to raise the alkalinity to pH 10-11, preferably to about pH 10.5. The alkaline hydrolysis reaction may be accomplished most effectively within the temperature range 50°C to 90°C maintained for two to four hours, preferably under pressure at about twenty pounds per square inch in a reactor including a recirculation mixer. The effectiveness of the hydrolytic reaction increases with temperature, time, and pressure, and these factors are also taken into account in adjusting the process to the characteristics of the raw sludge to be processed.

A unique feature of the sludge restructuring process of our invention is that the combination of homogenization, enzyme hydrolysis, and alkaline hydrolysis at elevated temperature and pH, serves to destroy practically all viral, bacterial, and parasitic microorganisms.

A feature of the alkaline hydrolysis step of our invention is that at pH 10.5, practically all metals which were soluble at lower pH are converted into

metallic hydroxide, semi-solid forms suitable for subsequent removal.

5 The resultant hydrolyzed intermediate product is conveyed to a mixing tank 7 to which chemical conditioners 8 may be added to facilitate subsequent removal of particulates and certain chemicals. For instance, a surfactant is usually added to reduce surface tension, thus to facilitate subsequent removal of particulates, including metallic hydroxides. If phosphate is present
10 in soluble form, ferric chloride may be added to precipitate this material in form suitable for subsequent removal.

The resultant hydrolyzed and conditioned intermediate product 9 is conveyed to particulate solids
15 removal equipment 10. Therein, centrifugal separators are preferably used to remove particulate matter. Such matter includes biologically-resistant fibrous solids and granular non-biodegradables, including metallic hydroxides, grit, ash, and biodebris. These residual
20 solids may be economically dewatered by air drying or by use of a relatively low pressure filter press. This residue is practically non-biodegradable and non-pathogenic since the pH is about 10.0 and practically all the microbiological life forms have been inactivated in
25 the prior hydrolytic reactions.

The thermally volatile content of the residue 11, including fibers, resin, and plastics may be reduced by autogenous combustion to a relatively low volume ash concentrate which may be refined to recover individual
30 metals such as cadmium, chromium, nickel, and silver.

The alkaline (approximately pH 10.5) BioFeed-stock intermediate product 12 is neutralized in a gas scrubber reactor 13 by chemical reaction with the carbon dioxide content of the digester gas 14 produced in an
35 aerobic digester reactor 15. Such reactors, well known in the art, are usually vertical cylindrical tanks, approximately 35 feet high, with static mixer-diffusers,

and operated at an average pressure of about 20 psi. The unique benefits of this reaction in the method of our invention are (a) the pH value of intermediate Bio-Feedstock 12 is economically neutralized to about pH
5 7.5; (b) this reaction is relatively stable at pH values in the range 7.5 to 10.5; and (c) the quality of the relatively non-soluble methane gas 17 released at the top of reactor 13 is substantially increased by removal of the carbon dioxide. The quality of the methane fuel
10 17 is further enhanced by absorption into BioFeedstock 16, of hydrogen sulfide gas and other non-fuel constituents often present in digester biogas.

The BioFeedstock 16 thus produced is a unique product of our invention. It contains biologically
15 available nutrients in soluble and microparticulate form suitable for relatively rapid microbiological metabolism. The potential for biologically incompatible reactions is substantially reduced by the prior hydrolytic steps of our invention which serve to disintegrate the molecular and cellular structures of micro-organisms in the inflow sludge 1. Thus, the protoplasmic constituents are made available for rapid assimilation by the anaerobic bacteria within the digester.
20

The digester sludge 18, including excess anaerobic microbial biomass produced in the process of digestion, is conveyed to liquid removal equipment 19. Therein, centrifugal separators and supplemental filters are preferably used to remove a low solids liquid effluent 20, without the use of flocculation chemicals.
30 Practically all of the particulate solids thus concentrated in sludge form at 21 are combined with the inflow of conditioned sludge 1 for subsequent restructuring, recycling, and conversion according to the method of our invention.

35 Alternatively, all or part of the inflow of conditioned sludge may be introduced into process at 22, directly into the digester 15. The resultant

bioconversion within the digester will be less rapid and less complete; however, the excess sludge residue will be concentrated and recycled 21 into nutrient Bio-Feedstock 16 and returned to digester 15 to complete the bioconversion process. In this arrangement, a reduced total volume of sludge solids 1 and 21 is restructured into BioFeedstock 16, and the equipment sizing and operating costs related to sludge restructuring and the removal of particulate solids and liquid effluent will be correspondingly reduced. The required digester capacity will be larger; however, this is not a disadvantage in retrofit installations where digester capacity already in place will be sufficient to handle the recycle load because of the operating efficiencies of our process.

Thus, the unique "full circle" process of our invention is employed to restructure and convert the biodegradable fraction of conditioned conglomerate sludges into methane gas, a liquid effluent, and a residue concentrate of non-biodegradable solids. Recalcitrant particulates that survive such restructuring, conversion, and liquid/solid separations will automatically be recycled via the full circle process until disintegration into low molecular weight constituents results in bioconversion in the digester or separation into liquid or solid fractions.

Referring to Figure 2, there is indicated a retrofit adaptation of the method of our invention to the functioning of a typical municipal wastewater treatment facility. The facilities added according to the method of our invention are indicated all inclusively at 41.

Raw wastewater influent 31 is processed through primary treatment 32 which may include removal of grit and trash and removal of settleable solids in the form of primary thickened sludge 22, typically 5-6% solids. This conditioned sludge is conveyed directly into

digester 15. Such primary sludge is well suited to anaerobic digestion since it includes a wide range of un-metabolized biological nutrients with a relatively low content of active incompatible microbial life forms.

5 The main flow of wastewater 33 containing over 50% colloidal and dissolved solids is processed through secondary aerobic treatment 34 to accomplish separation of solids 35 in the form of Waste Activated Sludge (WAS) and a clarified conditioned and disinfected
10 low solids effluent 36.

 In typical wastewater treatment plants, the WAS is thickened and conveyed directly into digester treatment. However, operational problems and inefficiencies result because the aerobic WAS biomass is bio-
15 logically incompatible with the anaerobic microorganisms which dominate the digester environment and because the content of non-biodegradable filamentaceous or fibrous solids cause agglomeration and foaming problems.

 In typical wastewater treatment plants, the
20 excess digester sludge 18, is dewatered to 20-30% solids and disposed of as wastewater treatment plant sludge. Dewatering costs are substantial, and operational problems and inefficiencies result because the recycled anaerobic effluent removed in dewatering operations is
25 biologically incompatible with the aerobic microorganisms which dominate the secondary treatment process. Waste sludge disposal costs are substantial because of the 70-80% liquid content and because of the biodegradable characteristics of most of the solids content.

30 In the Figure 2 adaptation of the method of our invention, the total discharge of excess digester sludge 18 is restructured as described with reference to Figure 1, numbers 2 through 17, to produce a BioFeed-stock product 16. Part of this flow of solubilized
35 nutrients 42 is recycled through flow-splitter valve 43 to the digester 15, combined with the input of primary thickened sludge 22. Valve 43 is adjusted to balance

the average flow of liquids 22 and 42 into the digester with the average flow of liquid sludge removed at 18.

The remainder of the flow of solubilized nutrients 44 is recycled through flow-splitter valve 43 to secondary treatment 34. Therein, excess water is removed for discharge as part of wastewater effluent 36, and the BioFeedstock nutrients are metabolized into additional waste activated sludge 35. WAS thickener equipment 45, preferably a centrifuge, is used to concentrate about 95% of the particulate solids in sludge form at 46. This is combined with the inflow of digester sludge 18 for subsequent restructuring, recycling, and conversion according to the method of our invention. The aerobic liquid effluent 47 removed by WAS thickener 45 is recycled to aerobic secondary treatment 34 without biological incompatibility problems.

Thus the unique "full circle" process of our invention is employed to restructure and convert the biodegradable fractions of sludges produced in metropolitan wastewater treatment plants into high quality methane gas and to correspondingly reduce the volume of solids discharged to waste. Additionally, the method of our invention is employed to improve the operations of metropolitan wastewater treatment plants by restructuring sludges in process to eliminate biological incompatibility reactions in interactive aerobic/anaerobic treatment processes.

Alternatively, additional conditioned sludges from other sources may be combined with the inflow of conditioned sludges 18 and 46 for subsequent restructuring and conversion according to the method of our invention. Such additional sludge inflows may include wastewater treatment sludge wastes from other municipalities or conditioned sludges prepared from the separated organic fraction of municipal solid wastes.

A preferred "Process for Treating Municipal Solid Waste" is described in U.S. Patent 4,540,495 issued

to Clifford C. Holloway. After classification to remove oversize objects and ferrous metals, the municipal solid waste (MSW) is treated with water, steam, heat, pressure, and agitation to produce a cooked, sterilized, and homogenized intermediate product. This is subsequently processed through size and specific gravity classification equipment to remove non-biodegradable objects. The resultant product contains substantially all of the biodegradable fraction of the MSW and is well suited for preparation of a conditioned sludge 1 for inflow to the restructuring and conversion process of our invention.

Alternative known processes have been described for separation of the conglomerate components of municipal solid wastes into biodegradable and non-biodegradable fractions. Such processes have employed combinations of dry and wet sorting, shredding, grinding, and other conditioning techniques. Examples of such resource classification and recovery techniques as described in the publications of Buhler-Miag, Inc., Minneapolis, Minnesota, and in publications about the Resource Recovery Facility owned by Metropolitan Dade County, Florida, developed by Parsons and Whittemore, New York, and operated by Resources Recovery (Dade County), Inc.

It is well known in the art to use gas scrubber reactors to refine digester or landfill biogas to produce high quality methane gas (typically 980-1,000 Btu/Scf) by removing carbon dioxide, hydrogen sulfide, and other undesired elements. Usually ordinary water or wastewater treatment plant effluent is used as the reactor counterflow liquid. Typically the inflow fluid has a pH value of about 7.0, and fluid discharge values are lower because of the reaction with the carbon dioxide which converts into carbonic acid. Since carbon dioxide is not readily absorbed into liquids at pH levels of 7.0 and lower, it is usually necessary to operate the

reactors at pressures up to 300 pounds per square inch. For reference, see BINAX system publications of Modular Products, Inc., Brea, California.

5 A unique feature of the method of our invention is the use of intermediate BioFeedstock product 12 at pH values above 10.0 as the inflow liquid to the gas scrubber reactor 13. As is well known in the chemical arts, infused carbon dioxide gas reacts readily with caustic liquids. The advantageous result obtained in
10 the method of our invention is that a given volume of raw digester biogas may be processed into utility grade methane fuel gas in smaller gas scrubber reactors, at lower rates of fluid flow, and at reactor pressures of only about 20 pounds per square inch.

15 In retrofitting modern municipal wastewater treatment plants with this Sludge Restructuring and Conversion Method, the digester 15 will usually be the existing digester(s), with capacities often exceeding one million gallons and designed for hydraulic retention
20 intervals of about 30 days. The hydraulic retention time required for processing a given quantity of biodegradable sludge solids may be reduced to about 4-6 days for a 100% inflow of restructured BioFeedstock in the system configuration of Figure 1. A somewhat longer
25 retention time may be required for the system configuration of Figure 2. In any event, the substantially reduced hydraulic retention time required for digesters operating within the methods of our invention may allow a reduction in the scale of digester operations or may
30 provide capacity for the treatment of additional conditioned sludges.

The BioFeedstock 16 product of our invention is well suited for use with anaerobic digesters designed for highrate conversion of readily biodegradable nutrient feedstocks having a minimal content of non-biodegradable materials. A preferred design is the Upflow Anaerobic Sludge Blanket (UASB) digester process
35

described in published papers by Jelte Lanting, et al., of Biothane Corporation, Camden, New Jersey. This digester design features internal concentration and separation of digester biogas, liquids, and solids into
5 separate discharge streams. Conversion efficiency is improved because of controllable selective retention of biodegradable solids within the digester. Laboratory tests indicate hydraulic retention times in the range
10 12 to 48 hours for system configurations illustrated in Figure 1. The internal separation or pre-separation of effluent and sludge residues discharged from the UASB Digester serves to reduce the cost and complexity of the liquid removal equipment 19.

EXAMPLE 1: A sample of BioFeedstock 16 derived from wastewater treatment sludge was tested for
15 its biological conversion characteristics in a laboratory scale, singlestage digester. During the initial 48 hours, digester gas was produced at a rate about eight times faster than for conversion of raw sludge.

EXAMPLE 2: A batch sample of wastewater treatment sludge was tested before and after the restructuring and removal of inert solids. We obtained an average
20 65% reduction in the concentration of the metals cadmium, chromium, copper, nickel, lead, and other metals.

EXAMPLE 3: Two batch samples of BioFeedstock 16 derived from restructured digester sludge were subjected to standard procedure analytical laboratory tests.
25 The following results were observed:

	<u>Sample A</u>	<u>Sample B</u>
30 Total solids	2.3%	2.2%
Soluble solids	2.3%	2.2%
Chemical Oxygen Demand	12,500mg/l	8,310mg/l
Biological Oxygen Demand	6,160mg/l	5,500mg/l

Machines suitable for use in the particulate
35 size reduction step 2 in the process of our invention

include a first stage sludge comminutor; e.g., the Gorator sludge grinding machines produced by Dorr-Oliver, Incorporated, Stamford, Connecticut, or the Maz-O-Rator machines available from Robbins and Myers, Inc.,

- 5 Springfield, Ohio. Subsequent processing may include the use of high-shear homogenization machines, e.g., the Dispax Ultra Turrax units produced by the Janke & Kunkel organization or the Sépratron machines produced by the Krupp organization, both in the Federal Republic
10 of Germany. Alternative particulate size reduction technologies may be used, as are well known in the art.

- Centrifuge machines well known in the art may be used for all or part of the liquid separation/solids concentration functions 10, 19, and 45 of Figures 1 and
15 2. Suitable high-speed, bowl-scroll machines for continuous flow operation are available from the Sharpless-Stokes Division of Pennwalt Corporation, Warminster, Pennsylvania, and from Bird Machine Company, Inc., South Walpole, Massachusetts. Conventional filtration equip-
20 ment may be used to supplement the liquid/solid separation processes.

- The hydrolytic enzymes employed in the process are added as an aqueous solution prepared from crude, dehydrated, nonspecific enzyme mixtures isolated from
25 microbial fermentation broths and subsequently dehydrated. Potency, depending on the enzyme involved, averages 50,000 international units of hydrolytic activity per gram as supplied by Worne Biotechnology, Inc., Medford, NJ. The hydrolytic enzymes may be rehy-
30 drated by dissolving 1 lb of dried enzymes in 5 gallons of water at 25°-37°C. This solution is added into the reactors in the ratio of 1 lb of dehydrated enzymes per 1000 lbs (dry weight) of biodegradable organic material inflow in the sludge to be hydrolyzed.

- 35 Hydrolytic enzymes useful for the purpose of this invention includes a wide variety of the following:

proteases	amylases	maltase
glucoamylase	dextranase	pentosanases
polysaccharidases	lipases	pectinases
protopectinases	hemicellulase	cellulases

- 5 These hydrolytic enzymes are capable of hydrolyzing proteins, carbohydrates, fats, protopectins, pectins, hemicellulose, cellulose, and polysaccharides into soluble, low molecular weight fractions.

- 10 For the protection and conservation of the sensitive and valuable protoplasm content of the cell, we usually limit the enzyme hydrolysis reaction to about 12 hours.

- 15 For large volume installations, mixed cultures of viable, dehydrated, hydrolytic enzyme-producing microorganisms may be employed as an inoculant. Potencies are typically about one million fungal spores per gram and about five billion viable bacteria per gram as supplied by Worne Biotechnology, Inc., Medford, New Jersey.

- 20 To establish a viable growing mixed culture capable of secreting the required quantities of enzymes, one pound of the inoculant is added to a 1,000 gallon stirred fermenter containing 750 gallons of sterile media of a type meeting the growth requirements of the specific microbial strains being cultured and designed to insure maximum enzyme production. Aerobic microbial cultures are provided with sterile air at a rate which gives a dissolved oxygen of approximately 2 ppm. Depending on the environmental requirements of the culture, the temperature is maintained between 20°C and 50°C, with an average of 25°C to 37°C. The media is adjusted to pH 4.5 to 7.5, the optimum being 6.5 to 7.0, depending on the cultures being grown. Anaerobic cultures used in the process receive identical treatment without the aeration. In about 24 to 36 hours, bacteria in the finished liquid culture will have a minimum cell concentration of 3 to 5 billion microorganisms per milliliter and will have reached the maximum level of enzyme

production. Due to slower growth rates, fungi will require a residence time of 3 to 5 days to reach maximum enzyme production.

The size of the vessel or vessels needed to grow the cultures and produce the enzymes averages 1,000 gallons per 250,000 gallons of liquid sludge slurry containing 10% solids.

The spent biomass should be separated from the enzyme rich media as soon as possible by filtration or centrifugal separation. After separation the biomass is added to the conditioned sludge feedstock for restructuring and conversion according to the process of our invention. About 90% of each batch of the enzyme rich media may be added to the enzyme hydrolysis reactor 3 at the rate of 50 gallons per 1,000 gallons of sludge slurry having 10% solids.

Ten percent of each enzyme batch, before separation of the biomass, may be retained for use as an inoculant for subsequent culture batches up to a total of five such extension cultures, after which a new series of cultures should be started with a fresh supply of dehydrated microorganisms as the inoculant.

Thus, in large installations a microbial inoculant, plus its exocellular enzymes, may be produced economically on site from relatively small amounts of commercially produced dehydrated enzyme-producing microorganisms.

Enzyme-producing microorganisms useful for the purpose of this invention include:

30	Athelia sp.	Myricoccum sp.
	Alternaria sp.	Thermonospora sp.
	Arthrobotrys sp.	Thermopolyspora sp.
	Arthrographis sp.	Xanthomonas sp.
	Beauveria sp.	Aspergillus sp.
35	Botrytis sp.	Acremonium sp.
	Cephalosporium sp.	Memnoniella sp.
	Chaetomium sp.	Metarrhizium sp.

	Chrysosporium sp.	Monascus sp.
	Cladosporium sp.	Mucor sp.
	Conidiobolus sp.	Mortierella sp.
	Coprinus sp.	Myrothecium sp.
5	Cytophaga sp.	Paecilomyces sp.
	Endothia sp.	Pellicularia sp.
	Entomophthora sp.	Penicillium sp.
	Eupenicillium sp.	Polyangium sp.
	Fomes sp.	Polyporus sp.
10	Fusarium sp.	Preussia sp.
	Gliocladium sp.	Pythium sp.
	Gliomastix sp.	Rhizomucor sp.
	Acinetobacter sp.	Rhizopus sp.
	Bacillus sp.	Sporoboromyces sp.
15	Achromobacter sp.	Serratis sp.
	Arthrobacter sp.	Stachybotrys sp.
	Corynebacterium sp.	Trichoderma sp.
	Cellulomonas sp.	Verticillium sp.
	Clostridium sp.	Candida sp.
20	Micrococcus sp.	Saccharomyces sp.
	Streptomyces sp.	Saccharomycopsis sp.
	Micromonospora sp.	Torula sp.
	Pseudomonas sp.	Yarrowia sp.
	Nocardia sp.	Mycrobacterium sp.
25	Thermoactinomyces sp.	

The digester fermentation and microbial growth are dependent on the optimal supply of nutrients. The bacteria have simple nutrient requirements; and the various organic materials required by some species, such as B vitamins, a small number of amino acids, or fatty acids, are supplied by other bacterial species. Inorganic minerals are usually the only other nutrients required. Most of the crude substrates utilized for methane fermentation contain sufficient minerals to satisfy the nutrient requirements for growth of the microorganisms; however, supplementation with

relatively minor amounts of nitrogen, phosphorus, and other nutrients may be advantageous.

All or part of the unique BioFeedstock product of our invention, available at 12, may be used alternatively as a high performance liquified fertilizer, usually distributed in irrigation water. This biologically available nutrient may also be useful in hydroculture crop production or in the production of algae or aquatic plants. More complete information about such alternative uses has been published in our U.S. Patents No. 4,267,049 and No. 4,432,650.

For purposes of clarity and understanding, the foregoing improved Sludge Restructuring and Conversion Method has been described in some detail by way of illustration and example; however, it is to be understood that certain additions, modifications, and omissions may be practiced within the spirit of the invention as limited only by the scope of the appended claims.

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WHAT IS CLAIMED IS:

1. A method for converting biodegradable
sludge to a gaseous fuel comprising:
 - 5 (a) hydrolyzing said sludge with hydrolytic
enzymes;
 - (b) further hydrolyzing said sludge by alka-
line hydrolysis to solubilize the biodegradable content
of said sludge;
 - 10 (c) removing non-solubilized solids from
said hydrolyzed product;
 - (d) neutralizing the product of said alka-
line hydrolysis; and
 - (e) anaerobically digesting said neutralized
15 product to form a gaseous fuel.
2. The method for converting biodegradable
sludge in accordance with claim 1, wherein there is a
non-gas residue following the anaerobic digestion of
20 step (e), and said non-gas residue is recycled through
steps (a) through (e).
3. The method for converting biodegradable
sludge in accordance with claim 2, including the step
25 of reducing the liquid content of said non-gas residue
before it is recycled.
4. The method for converting biodegradable
sludge in accordance with claim 1, wherein conditioned
30 biodegradable sludge is combined with said neutralized
product in the anaerobic digestion of step (e).
5. The method of converting biodegradable
sludge in accordance with claim 2, wherein conditioned
35 biodegradable sludge is combined with said non-gas res-
idue and recycled therewith.

6. The method of converting biodegradable sludge in accordance with claim 1, wherein said neutralizing step (d) is executed to adjust the pH of the product to about 7.5.

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7. The method of converting biodegradable sludge in accordance with claim 1, wherein said neutralizing step (d) is executed by contacting the solubilized portion of the alkaline hydrolysis product with the gas formed in the anaerobic digestion of step (e).

8. The method of converting biodegradable sludge in accordance with claim 7, wherein said contact is executed in a gas scrubber with the solubilized portion of the alkaline hydrolysis product at a pH of about 10-11 whereby said neutralizing step (d) occurs by reaction with carbon dioxide present in said gas.

9. The method of converting biodegradable sludge in accordance with claim 8, wherein contact between the alkaline hydrolysis product of step (b) and said gas causes said alkaline hydrolysis product to remove hydrogen sulfide from said gas and thereby provide a gas of increased methane content.

10. A method for converting aerobically treated biodegradable sludge to a gaseous fuel comprising:

30 (a) hydrolyzing said aerobically treated sludge with hydrolytic enzymes;

(b) further hydrolyzing said sludge by alkaline hydrolysis to solubilize the biodegradable content of said sludge;

35 (c) removing non-solubilized solids from said hydrolyzed product;

(d) neutralizing the product of said alkaline hydrolysis; and

(e) anaerobically digesting said neutralized product to form a gaseous fuel.

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11. The method for converting aerobically treated biodegradable sludge in accordance with claim 10, wherein said aerobically treated biodegradable sludge is sludge formed by secondary treatment in a waste water treatment plant.

12. The method for converting aerobically treated biodegradable sludge in accordance with claim 11, wherein said neutralizing step (d) is executed by contacting the solubilized biodegradable content of step (b) with the gas formed from the anaerobic digestion of step (e).

13. The method for converting aerobically treated biodegradable sludge in accordance with claim 12, wherein there is a non-gas residue following step (e), and said non-gas residue is recycled through steps (a) through (e).

14. The method for converting aerobically treated biodegradable sludge in accordance with claim 13, wherein a portion of said neutralized product of step (d), related to the amount of non-gas residue being recycled from step (e), is returned and mixed with activated sludge formed by secondary treatment in a waste water treatment plant and the mixture subjected to steps (a) through (e).

15. A process for converting biodegradable waste to gaseous fuel in which the biodegradable waste is solubilized by alkaline hydrolysis, including the steps of neutralizing the solubilized biodegradable

waste and anaerobically converting the neutralized waste to fuel gas, said neutralization being executed by contacting the alkaline hydrolyzed biodegradable waste with the fuel gas produced by said anaerobic conversion.

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16. The process for converting biodegradable waste to gaseous fuel in accordance with claim 15, wherein said alkaline hydrolyzed biodegradable waste is at a pH of about 10-11, whereby carbon dioxide in said fuel gas neutralizes said solubilized biodegradable waste to a pH of about 7.5.

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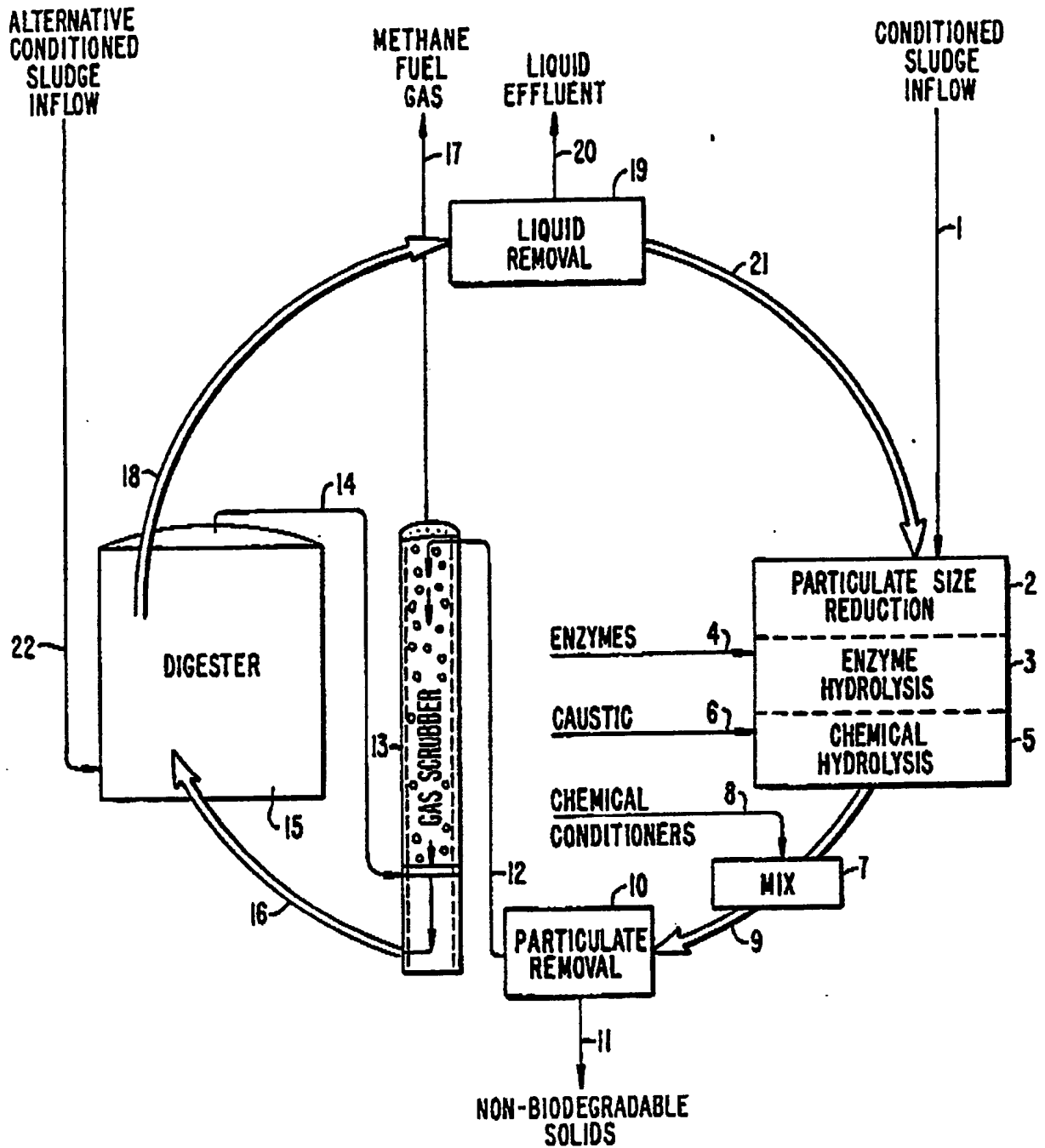
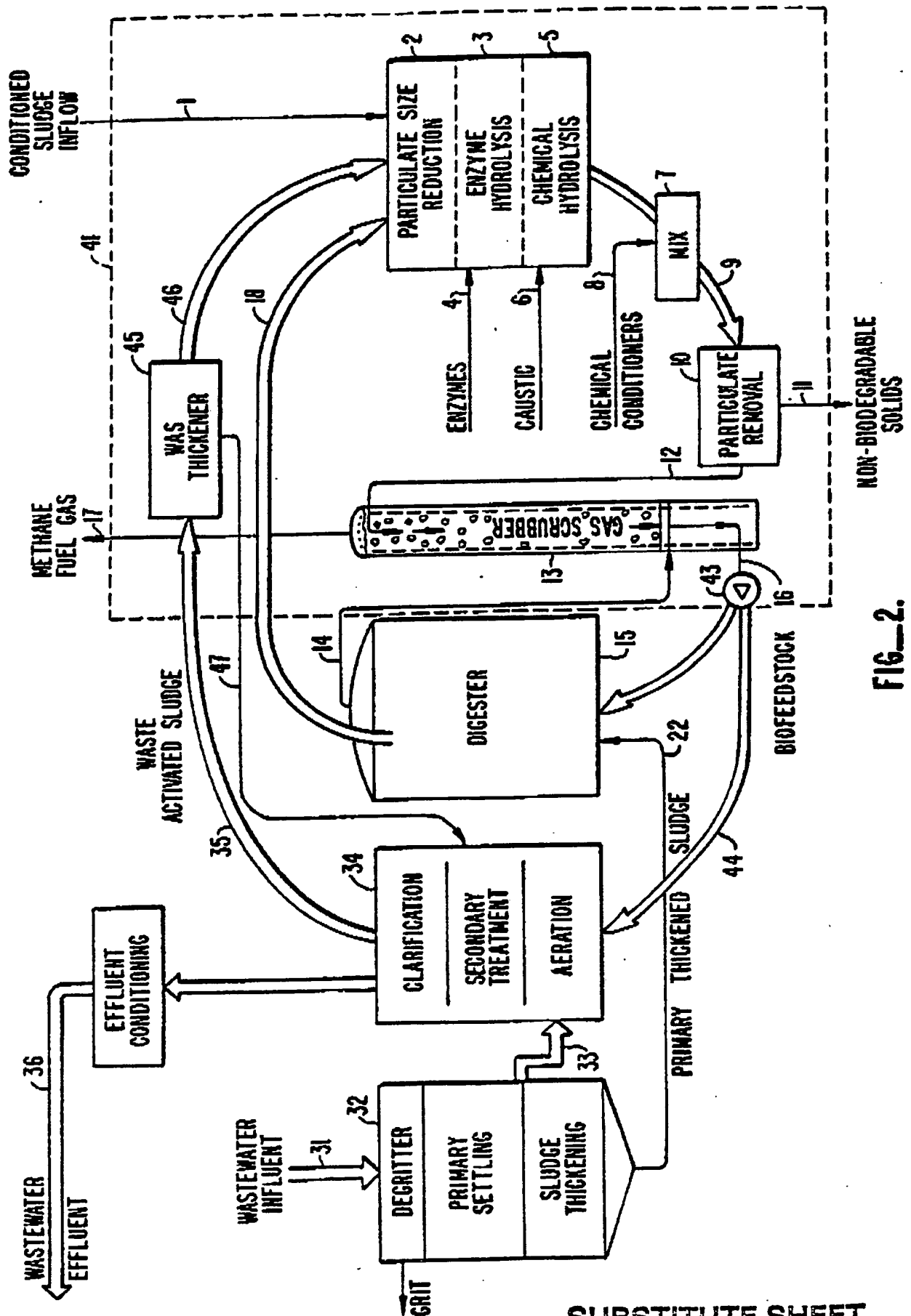



FIG. 1.



INTERNATIONAL SEARCH REPORT

International Application No **PCT/US87/01477**

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC(4): C02F 11/04 C02F 11/14		
U.S. Cl: 210/603, 606, 613, 631, 632 435/167 71/12		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	210/603, 606, 613, 631, 632, 688, 731, 912 71/12, 13, 14 435/167, 253	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category ⁶	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
Y	US, A, 4,342,650 (ERICKSON ET AL) 03 August 1982, See the entire document.	1-16
Y	US, A, 3,622,507 (PASVEER) 23 November 1971 See the entire document.	1-16
Y	US, A, 3,915,853 (LUCK) 28 October 1975 See the entire document.	1-16
A	US, A, 4,504,394 (BREUER ET AL) 12 March 1985.	
A	US, A, 3,994,780 (KLASS ET AL) 30 November 1976.	
A	US, A, 4,132,638 (CARLSSON) 02 January 1979.	
A	US, A, 3,979,286 (WING ET AL) 07 September 1976.	
A	US, A, 4,491,522 (ISHIDA ET AL) 01 January 1985.	
A	US, A, 4,267,049 (ERICKSON ET AL) 12 May 1981.	
<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p>¹⁵ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 48%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²	Date of Mailing of this International Search Report ²	
29 September 1987	20 OCT 1987	
International Searching Authority ¹	Signature of Authorized Officer ²⁰	
ISA/US	 Benoit Castel	